THE U.S. BUREAU OF MINES PROGRAM TO CONTROL RESPIRABLE DUST IN COAL MINES

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INTRODUCTION

Inhalation of dust has long been recognized as a health hazard leading to pulmonary diseases. In the 16th century, Agricola, the father of mining, discussed dust inhalation during mining and called it a "widow maker." In the 19th century the "black lungs" of autopsied coal miners were recorded. The 11th Edition of Encyclopedia Britannica, some 60 years ago, described fibroid changes and included a graphic photomicrograph of a cross section of a coal miner's lung.

The Federal Coal Mine Health and Safety Act of 1969 (PL 91-178, December 30, 1969) established health standards in underground coal mines for the first time in the United States. The Act specifically stated that the working conditions in each underground coal mine should be sufficiently free of respirable dust to allow each miner to work underground without incurring any disability from coal workers' pneumoconiosis (CWP) or other occupation-related disease during his working life. Based largely upon British studies, the Act specified that the maximum allowable concentration of airborne respirable dust particles (nominally less than 7.1 μm in diameter) in bituminous coal mines should be 3 mg/m^3 by June 30, 1971 and 2 mg/m^3 by December 30, 1972. The maximum permitted dust level is decreased if the silica content of the dust is greater than 5 weight percent so that the Threshold Limit Value (TLV) of 100 $\mu g/m^3$ of silica for an eight hour exposure will not be exceeded.

CWP is the most severe health and safety problem facing the coal mining industry today.

1. The number of permanent disabilities and deaths of coal miners due to CWP is 3.5 times the disabilities and deaths due to all other mine accidents (1964-1970 Pennsylvania data). (1)

2. About 30 percent of the present working miners have CWP (1972).

3. About 165,000 claims for CWP have been approved and some 100,000 additional claims are currently under review.

The cost to Government and industry for CWP compensation has been estimated to be $1 billion per year.

However, it has been estimated that coal production must double by the year 2000 in order to meet the energy requirements of the nation. The necessity for society to devise methods for mining coal at a rapid and economical rate while maintaining a healthful mining environment is apparent.

The 1969 Act directed that the Departments of the Interior and Health, Education and Welfare shall "develop new or improved means and methods of reducing the concentrations of respirable dust in the mine atmospheres of active workings of the coal mines." The Bureau of Mines was assigned the responsibility for planning and implementing a research and development (R&D) program to provide the advanced technology for reducing the amount of respirable dust in coal mines. This advanced technology would assist the mine operator to meet the stringent dust limits imposed by the Act.

The present problem of dust control during coal mining operations is considerably different from the problems normally encountered during industrial operations. For example, coal is often mined underground using continuous (mechanical) mining methods,* where coal is removed by cutting bits on a rotating wheel or chain. Dust is formed by the cutting action of the bits, and also at nearby locations by secondary handling operations. Water sprays are used to suppress the dust being formed by the cutting action. Also, air is passed over the machine to the face and then back behind a brattice cloth (usually) to "push" the dust away from nearby personnel. However, dust control during actual coal mining operations is not so clear-cut. An analogy to a typical industrial operation would be to devise ways to control a hazardous impurity in a chemical processing plant where:

1. the sources of the impurity (dust) are imperfectly known;

2. laboratory and pilot plant information is of limited usefulness (it is almost impossible to simulate the underground mining situation in the laboratory);

3. the amounts of the impurity are variable (cutting bits become broken, cutting rate varies with machine operator);

4. the flows in the plant are ill-defined and highly variable, e.g., a pipe (spray nozzle) plugs, the flow through a main pipe changes intermittently and irregularly (the distance of the brattice cloth to the face changes);

5. the chemical process varies (variety of coal seams, variation of coal structure in a seam and in a given mine, variety of mining machines);

6. imperfect operating equipment (numerous equipment malfunctions in the rugged mine environment);

7. inadequate sampling equipment (long-duration dust samplers to determine transient dust concentrations);

8. erratic sampling equipment (difficult to scientifically sample airborne dust);

9. hostile environment (a 30-inch-high seam, roof falls down).

The Bureau's program has been divided into four general categories: dust control, personal protection, instrumentation, and chemical analysis. Expenditures are summarized as follows:

	FY 70	FY 71	FY 72	FY 73 (estimated)
		($1.000)		
Dust control	1,168	2,176	1,639	1,523
Personal protection	32	90	106	-
Instrumentation	270	447	253	379
Chemical analysis	168	227	347	135
	1,638	2,940	2,345	2,037 (estimated)

*About 50 percent of the coal mined underground in the United States is obtained by continuous (mechanical) mining, 47 percent by conventional (blasting) mining, and 3 percent by longwall (mechanical) mining. This paper is limited to dust control by the first mining technique.

The program involves inhouse work at two Bureau research facilities, Twin Cities Mining Research Center and Pittsburgh Mining and Safety Research Center, and also an assortment of contracts and grants with outside organizations.

This paper briefly describes the major items in the Bureau program and their status.

DUST CONTROL

Continuous mining machines were designed to mine coal at a fast rate. They are very efficient mining machines. However, by using blunt high-speed bits, they probably are the best machines for forming dust that could be invented, except for a grinding stone.

Bureau research has shown that continuous mining forms approximately 5,000 grams of respirable dust at the face per ton of mined coal. About 2 grams of this dust becomes airborne at the face; the remainder remains adhering to the run-of-face broken coal.

An exploratory statistical study indicated that the same mining occupations in different seams often had significantly different dust exposures. For example, the continuous miner operator in the Pittsburgh and Pocahontas seams is exposed to more dust than the same man in the Kittanning seam, but curiously, the Kittanning seam gives more dust along a haulage road than the other seams. Such information suggests basic differences in the dust-forming characteristics of different coal seams, but the explanation for these differences is not presently known.

Dust control techniques at the face include:

available technology
machine cutting parameters
supplementary ventilation; dust collector
water sprays
wetting agents
pick flushing
foam
infusion

These items are described and are followed by a concluding section discussing secondary dust:

<u>Available Technology</u>. Considerable technology is already available, but it is often not effectively used because of inconvenience or expense. For example, while water sprays provide a valuable dust control technique, their practical usefulness underground is limited because they frequently clog in the rugged mine environment. Cleaning or replacement of a clogged nozzle is expensive to the mine operator in terms of time and cost. The development of a non-clogging spray nozzle system would reduce operator expense and inconvenience and therefore would increase the actual effectiveness of water sprays as a dust suppression technique. A contract to develop a non-clogging nozzle is expected to be awarded in late FY 73.

<u>Machine Cutting Parameters</u>. The British conducted pioneering work examining the effect of machine parameters on the formation of airborne dust and concluded that sharp, slow-moving, deep-cutting bits produce less dust. The problem now is to obtain quantitative information on the amount of airborne dust versus machine parameters with American coal and mining methods, along with cost and other engineering information. Improvement in cutting parameters is estimated to offer a 50-percent decrease in airborne dust.

A full-scale machine which permits varying of the machine parameters (rpm, sump and shear rate, bit geometry and array) is being constructed by Ingersoll-Rand under Bureau contract. The machine will be automatically controlled to avoid operator variables and will be used in full-scale underground tests to obtain the desired information on the effect of the machine parameters versus dust formation. Also, a research mining machine having a single full-scale cutting wheel was designed and constructed. This research machine permits the machine parameters to be varied over a wider range than the full-scale machine and will be used as a "pilot plant" to further investigate the effect of cutting parameters on the formation of respirable dust. Finally, several laboratory programs are investigating dust formation during cutting in order to better understand the fragmentation process. Such studies hopefully will lead to new bit designs and the selection of machine parameters that reduce dust production.

Supplementary Ventilation. Air flow at a mining face is normally controlled by line brattice or by extensible tubing, occasionally in conjunction with an auxiliary fan. However, supplementary ventilation techniques that involve machine-mounted fans to draw or exhaust the dusty air from the vicinity of the face appear very attractive for dust control because they reduce the recirculation of face dust back to nearby personnel and can in principle be applied to various kinds of continuous mining machines and local mining situations. A disadvantage of this local exhaust approach is that the dusty air must either be discharged into the return via a duct or be passed through a machine-mounted dust collector with the partly cleaned effluent air being discharged at the mining machine.

A current program is examining the exhaust approach with an auger-type mining machine in low coal. A machine-mounted dust collector is used, but the effluent air is ducted into the return. The unit is presently being tested underground. Initial results are encouraging, but additional testing is required.

A severe problem in coal mines, especially in low coal, is the space limitation. For example, the available high-cfm fans were too large to install on the low-coal auger machine and two small-cfm fans had to be used in parallel. This was undesirable from an engineering viewpoint but was the only alternative at the time. It has since been established that technology is indeed available to fabricate a high-cfm, small-diameter fan suitable for operation in low coal, and a prototype unit is being constructed inhouse. The availability of such a fan would expedite the use of supplemental ventilation techniques in low coal and other areas where space limitations are critical.

Passing the exhaust dusty air through a machine-mounted dust collector has mushroomed in popularity during the past year. This approach has the distinct advantage of avoiding ducting from the machine to the return. However, the dust collector must be very efficient because any effluent dust may bathe the machine operator and nearby personnel and could even increase their dust exposure. Available dust collectors tested in 1970, comprising a large assortment, were all found unsatisfactory because of a low collection efficiency for respirable size dust or because of bulk or safety problems. The Bureau has fabricated an above-ground facility to evaluate the collection efficiencies of new full-scale collectors as they become available. For example, the collection efficiency of a typical scrubber designed for mounting on the boom of a continuous miner ranged from 80 percent for 1 micron dust to 99 percent for 5 micron dust. While surprisingly high, these efficiencies are still too low to scrub anticipated incoming dust levels to a 2 mg/m^3 level.

A venturi wet-collection approach appears to be the most attractive mechanical approach for achieving high collection efficiency. A Bureau-designed research-type venturi collector will be used to investigate collection efficiency versus power input, water flowrate, and other engineering parameters. Results will provide guidance for the design of dust collectors for specific situations and can assist a mine operator to determine whether a mechanical collector will bring him into compliance. In the interim, the Bureau is fabricating a new, simpler, low-cost, venturi collector that is especially designed for use in coal mines.

An alternative and new approach for a respirable dust collector is to use plastic surfaces such as polystyrene and polyethylene. Such materials usually have "islands" of electrical charge that rapidly collect airborne coal dust if the dust has an electrical charge. Exploratory inhouse underground tests have shown that mine dust often has an electrical charge and that an appreciable collection can be obtained merely by passing the dusty air through a plastic tube. In principle, such collection should be especially effective for smaller particles because of their higher mobility. In view of the difficulty of collecting very small particles, the feasibility of a plastic-type dust collector for coal mine use is being explored.

In general, the air flow pattern in the vicinity of the mining machine and at the face is crucially important in affecting the transport of face dust back to the machine operator and nearby personnel in exhaust ventilation. However, local flow patterns are largely unknown. Since the machines usually occupy a large fraction of the cross section of an entry, their presence would be expected to significantly influence flow patterns. Recent inhouse work confirmed this expectation and also found that the motion of the cutting wheels influences the local flow pattern.

A 1/10-scale laboratory model of a low-coal entry including the auger-type mining machine is being used in an inhouse study of local flow patterns and the effect of these patterns on the transport of respirable dust. This work supports the low-coal field contract. Results to date indicate that drawing about half of the incoming ventilating air through the machine leads to a drastic reduction of the dust levels at typical personnel locations. Modeling appears very attractive as an inexpensive technique for screening proposed auxiliary ventilation techniques before underground testing is initiated. Underground measurements are currently being made to verify the modeling concept.

Water Sprays. One of the main dust control techniques presently in use is water sprays. Sprays are reported to reduce the respirable dust level 20 to 60 percent, although 30 percent is a typical number. The type and placement of spray nozzles is currently selected in an arbitrary manner because guidelines are not available; a typical approach seems to be to merely add more nozzles in the hope of reducing more dust. Techniques seemingly could be devised which would make a more effective use of the sprays, e.g., either greater dust suppression with the existing water flow or sufficient suppression with a smaller water flow rate.

British laboratory studies indicated that the capture of airborne respirable-size particles with water drops is dependent upon the size, concentration, and velocity of the drops, although optimum spray parameters to be used to achieve maximum dust suppression for underground spray systems were not determined.

A Bureau program to determine these optimum parameters for a spray system was undertaken. A theoretical model for the capture of airborne dust was developed and verified in the laboratory. Capture efficiencies of up to 75 percent were obtained. The theory can be used to select an optimum spray nozzle which gives the maximum collection efficiency of airborne dust at a specific spray-nozzle location in a mine for the water flowrate, line pressure, and geometry at that location. In practice, of course, the water spray drops can also impact and moisten the surface of coal and thereby suppress the formation of airborne dust by interfering with the dust-forming cutting process or by enhancing the adhesion of newly-formed particles. The development of a theoretical impaction model is being studied inhouse. Combination of the impaction and airborne models will then be attempted.

In the interim, the usefulness of the above airborne theory for improved dust suppression at the front end of a continuous mining machine was tested underground. In one test series, dust suppression was about equal with all spray nozzles, although the "good" sprays used about one-third less water than other sprays. In another less extensive series, the good sprays also gave one-third less dust. The use of one-third less water is a major accomplishment because many mines already have excessive moisture. Additional underground testing is required to obtain definitive data regarding dust suppression.

Another Bureau program indicated that steam and water spray were about equal in effectiveness for suppressing the formation of airborne dust or for collecting airborne dust. The use of steam underground would involve difficult logistics and is not recommended.

Wetting Agents. The usefulness of wetting agents for increasing the effectiveness of water sprays as a dust control technique is controversial. Some workers state that they are worthless, others state they are helpful, and there is little published data to support either statement. Clarification is warranted in view of the expense and inconvenience associated with using such agents. The Bureau had a contractor measure the wetting behavior of 16 wetting agents on coal from six different seams. All agents essentially wetted all the coals. At present, another contractor is measuring the drop size and velocity of the sprays from several nozzles with several wetting agents. Underground tests will be conducted to establish the usefulness of wetting agents as a dust suppression technique.

Bit Flushing. British studies indicated that a 75 percent reduction in dust is obtainable by directly flushing the cutting bits with water. However, internal plugging of the orifices and seal leakage have prevented this technique from being widely used in the United States. Although approximately 40 such "wet-head" machines are underground, only two are reported to be using the wet-head mode. A contractor has designed an improved seal with one type of wet-head ripper machine and is presently conducting underground tests.

Foam. The use of foam for dust suppression is based on the concept of using a high-expansion foam to "blanket" the cutting site and thus physically prevent any dust from becoming airborne. Several studies to establish the merit of foam have been attempted over the past 10 years, but results were inconclusive because of insufficient underground testing. The Bureau therefore initiated a new, more detailed effort in order to obtain definitive results on the usefulness of foam. Brief underground tests in FY 72 established that the foam broke rapidly, that there were no slip hazards, and that the foam was well received by mine personnel. However, the underground testing regarding dust suppression was inconclusive, and the program is being continued to obtain sufficient data in order to be statistically significant.

Infusion. Water infusion has been useful in Europe for reducing dust formation during subsequent mining. German mining regulations require water infusion wherever possible as a dust control technique, but implementation seemingly is left to the discretion of individual mines. About 15 percent of the collieries in England are using infusion to control dust but are having problems due to the low permeability of English coal beds.

Infusion has received only limited attention in the United States owing to engineering-type equipment problems. The Bureau initiated an infusion program with the dual objectives of controlling methane and reducing the formation of the dust. To date, significant methane control has been achieved and dust seemingly is reduced by about 50 percent. However, considerable additional field work is required to obtain definitive results.

Secondary Dust Generation. Points of secondary dust generation include the gathering arms on the continuous mining machine or loader, dumping of material into the shuttle car, operation of the shuttle car along the roadway, belt operation, belt transfer points, etc.

Inhouse Bureau work has shown that enough respirable-size coal dust adheres to 20 pounds of ordinary run-of-face broken coal to contaminate approximately 1 million cu ft of air up to the 2 mg/m^3 level if it should become airborne. The potential danger of secondary hauling as a dust source is obvious. The magnitude of the forces involved in physical adhesion of coal particles to massive substrates was measured and found to approximately agree with expected adhesion forces.

Laboratory work indicates that only about 10 percent of the dust adhering to the run-of-face coal is dislodged and becomes airborne during a typical drop operation. Dust generation can be reduced only somewhat by changing the belt parameters, e.g., the dust would be reduced by about 30 percent by decreasing the drop height or slowing the belt by a factor of 2. A 70-percent reduction of dust should be obtainable by passing the broken coal down an inclined chute instead of a vertical drop or by using water sprays along the belt somewhat upstream of the drop point. These laboratory conclusions have not yet been tested in a full-scale operation.

At an underground belt transfer point, water sprays or a low-expansion foam injected directly into the falling coal reduced the formation of airborne dust by about 50 percent. Additional application of water sprays onto the underside of the belt reduced airborne dust by 60 percent, while foam on the underside of the belt reduced dust by 90 percent.

Laboratory research indicates that the formation of new dust due to secondary breakage during dropping is insignificant compared to the dislodgment of adhering dust.

PERSONAL PROTECTION

While the Bureau does not consider personal protective devices such as face masks as a primary approach for reducing the miner's exposure to dust, such personal protection can be visualized as an interim measure and also as a "last alternative" for certain dusty operations in case remedial measures are unsuccessful. The present filter-type face mask is undesirable because of (1) a high-pressure drop when clean and an excessive pressure drop during use due to plugging, (2) an imperfect match to the facial contour, (3) poor day-to-day refit in the field, (4) irritation due to dust at the mask-face juncture, and (5) interference with voice communication, spitting, etc.

A personal device employing the air curtain concept is presently being developed under Bureau contract. Dusty air from the environment is filtered and an air curtain of dust-free air is passed from the hat brim down over the miner's face, thereby shielding him from the dusty environment. Such a unit requires considerable power and therefore is limited to machine operators but hopefully will be of interest to industry in general.

INSTRUMENTATION

Improved dust samplers for monitoring the eight-hour exposure of miners and also for research purposes are required. The state-of-the-art in dust sampling is aptly summarized in an International Labor Organization report (1967), which concludes that "No evaluation or comparison of dust content has any significance... unless the type of equipment, the method of sampling, and the nature of the dust are precisely known."

The dust hazard in United States mines currently is assessed gravimetrically with a personal sampler continually worn by the miner during his working shift. The sampler uses a battery-powered pump to draw 2 l/min of dusty air through a cyclone, which collects the nonrespirable dust, and then through a membrane filter, which collects the respirable fraction. The filter is weighed in the laboratory to determine the total mg/m^3 of dust exposure; 2 mg of weighed dust approximately corresponds to 2 mg/m^3 exposure for eight hours.

Although this system functions, the weight and size of the personal sampler is burdensome to the miner, the sampler is subject to mischief, the entire approach is expensive, and the accuracy of the system has been questioned.

Bureau research has indicated that about half of the 1 to 2 μm underground airborne particles are agglomerated to large nonrespirable airborne particles. This means, unfortunately, that a size classifier must be used with any sampler, i.e., the sampler merely cannot collect all the dust and the respirable fraction measured in the laboratory, for the respirable dust concentration then would be overestimated.

Respirable dust nominally involves 7.1 μm-diameter or smaller particles and is specifically defined by the Act in terms of the size classifier of the British MRE dust sampler. However, medical authorities are seriously considering revising the TLV standard for silica to emphasize the smaller size particles. Also, some medical workers feel that dust particles somewhat larger than the respirable fraction may lead to some respiratory diseases, while others feel that the submicron particles are especially dangerous to human health. Furthermore, medical authorities are becoming increasingly concerned that short exposures to high dust levels may be more hazardous than the eight-hour time-averaged value of the dust exposure, which is the present basis of the dust standard.

Research purposes require a short-duration, fast-response field sampler to test the effectiveness of a dust control technique and to assist the identification of dust sources. The present midget impinger unit requires about 10 minutes to obtain sufficient dust for analysis by the Coulter counter. This technique is reasonably satisfactory for screening, comparison-type purposes. However, a 10-minute sample time is excessive for monitoring many mining operations owing to the short duration of the operation.

Light scattering is attractive because response time is rapid and the electrical output signal can be readily measured and could be telemetered or used in control circuitry. However, light scattering is related to the area of the particles in a dust cloud, and results must be converted to mass concentration (mg/m^3). With laboratory dust, this conversion is reasonably reproducible. With mine dust, the size distribution varies, and variable amounts of noncoal materials that have different densities and indexes of refraction are often present. Such variations will lead to a variable (and unknown) conversion factor. Despite the potential uncertainty in the conversion factor, a prototype unit was fabricated by a contractor. The unit has a fast response time (5 seconds) and already has been valuable in underground work as a "screening" tool.

CHEMICAL ANALYSIS

The 1969 Act specifies a maximum exposure to respirable coal mine dust of 2 mg/m^3 but also stipulates that the permitted level is reduced below the 2 mg/m^3 standard to the value given by the expression 10/(percent quartz) to match the TLV of 100 $\mu g/m^3$ quartz for an eight-hour exposure. All the silica in a coal-mine dust sample is assumed to be quartz.

At present, the Bureau analyzes the quartz content in mine dust by removing the dust from about 10 personal respirable dust samples, combining the dusts, ashing the combined dust, making a KBr pellet of the ashed dust, and measuring the amount of silica in the pellet with infrared (IR) techniques. This approach is time consuming and expensive and, by combining the silica content of the several samples, does not give the eight-hour exposure of an individual.

A technique for analyzing the silica content of a single field filter sample was recently developed by the Bureau wherein the dust was removed and redeposited onto a new filter and then analyzed by IR and X-ray techniques. Results obtained by both techniques agreed, giving support to the values obtained by both techniques. However, the true accuracy of any of the mentioned methods is exceedingly difficult to determine. Also, the effect of particle size, the occurrence of other SiO_2 polymorphs, and perhaps surface effects must be examined.

Direct measurement of the silica in the mine dust as collected on the field filter sample would greatly expedite analysis and is being explored by the Bureau and a contractor using IR techniques and by another contractor using a new soft X-ray approach.

Recent work in West Germany indicates that silica dusts from different coal mines have significantly different toxicities despite similar particle sizes and concentrations. Considerable clarification of the hazards associated with silica by medical authorities appears necessary.

Medical researchers have become increasingly concerned that small quantities of inorganic and other materials in the coal mine dust may add to the health hazard. The Bureau initiated several programs to develop laboratory analytical methods to measure the concentrations of assorted materials in anticipation that standards may be established. In addition, techniques were developed for measuring the surface areas and density of different size fractions in the respirable dust, in anticipation that such information would be of medical value. However, medical authorities have been hesitant to promulgate new standards in these areas, and only one program examining carcinogenic organic compounds in respirable dust has been continued.

CONCLUSION

The final objective of the present Bureau program is to provide advanced technology to control airborne respirable dust in coal mines by 1975 and preferably earlier. An assortment of approaches is being explored, for it is unlikely that a single technique will be equally suitable for the diverse mining operations. The present respirable dust problem is almost unique in industry because controlled experiments are difficult to perform, dust samplers are imperfect, and the environment is exceedingly hostile.

REFERENCES

1. P. Dessauer, et al, Annals of the New York Academy of Sciences, v. 200, 1972, p. 220.